NORMAL TO SUPERCONDUCTING TRANSITION TIMES FOR THIN FILMS OF TIN AND INDIUM

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Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
PHYSICS

United States Naval Postgraduate School
Monterey, California

1 9 6 4

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ABSTRACT

The transition time from the resistive to the superconducting state for thin films of tin and indium was investigated under a variety of conditions. The purpose was to extend previous work which had shown that, when a thin film is switched to the normal state by a current pulse, the time required for the film to return to the superconducting state can sometimes be decreased by increasing the pulse amplitude. Thus the transition time is not a continuously increasing function of the current used to switch the film to the resistive state and hence cannot be entirely explained by joule heating and subsequent cooling by conventional heat transfer processes. The effects on the transition time produced by temperature, switching pulse duration, magnetic field and a silicon monoxide coating on the film were investigated.

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1. Introduction.

Experimental research on superconductivity has resulted in a long list of superconductors with known transition temperatures.[1] This list continues to grow and an understanding of the various properties of the superconductor becomes increasingly important as industrial uses are developed. Some of the proposed applications depend on the dramatic difference in the resistance of a conducting circuit element when it undergoes transition to and from the superconducting state. For such a transition it is often important to know how much time is required for each portion of a switching cycle. This paper is the result of an investigation of the time required for the transition from the normal to the superconducting state.

The superconducting state can be destroyed by a magnetic field. The smallest field that renders a bulk specimen resistive is known as the critical field, and for soft superconductors is generally a parabolic function of temperature. This function is given quite well by $H_c = H_o(1-(T/T_c)^2)$, where H_o is the critical field at 0°K, T_c is the critical temperature for zero magnetic field, and H_c and T are the values of interest. These fields are of the order of 1,000 gauss or less for most superconducting elements, but may be far greater for alloys. Recent investigations with alloys and compounds have led to the discovery of V_3Ga which appears to have a critical magnetic field of approximately 500 kilogauss.[2]

[1] Matthias, B. T., T. H. Geballe and V. P. Compton. Superconductivity. Review of Modern Physics, Vol. 35, Nr. 1, January 1963; 1-22.

[2] Jones, W. H., F. J. Milford and S. L. Fawcett. Status of Superconductivity. Battelle Technical Review, Vol. 11, Nr 9, September 1962: p5.

The magnetic field used to destroy the superconducting state can be generated by passing a current thru the specimen. Thin film circuit elements are frequently used as specimens in superconductivity investigations because their normal state resistance is much greater than that of bulk material. This makes the transition characteristic simpler to measure. To study this characteristic a pulsing technique is frequently used. The general procedure is to maintain a small direct current in the specimen, and then to apply a current pulse which drives the specimen resistive. When the pulse is removed the small direct current shows as a voltage drop across the specimen until it returns to the superconducting state. An oscilloscope is used to measure the current pulse as a voltage drop across a known resistance (Figure 1a). The voltage drop across the specimen due to these currents, as seen on an oscilloscope, is pictured in Figure 1b. When a thin film is pulsed with a current and driven resistive, the film returns to the superconducting state when the current is removed. This transition, from the resistive to the superconducting state, takes a measureable interval of time, which we shall call the "backswitch time" and is seen on the oscilloscope as the time required for the voltage drop due to the small direct current through the specimen to vanish.

When a superconducting film is driven resistive by passing a current through it there is an increase in its temperature due to joule heating. From an unsophisticated application of thermodynamics, one might expect the backswitch time to be a continuously increasing function as the current is increased. Previous investigations have shown this is not the general result[3]. In some cases the backswitch time is found to increase to a

[3] Lauer, A. C. and J. K. Nunneley. Transition Time From Resistive to Superconding State for Thin Indium Films, U. S. Navy Postgraduate School Thesis, 1959: p 8.

maximum, decrease to a minimum and then to increase again as the current is continuously increased (Figure 2). Hence an explanation of the back-switch time as a joule heating effect due to the current through the specimen while it is resistive does not offer an explanation for the appearance of a maximum and minimum in the curve showing backswitch time as a function of pulse current. The presence of a maximum and minimum indicates that there must also be other effects present.

This "backswitch anomaly" is the subject of the experimental investigations reported on in this paper.

2. Experimental Procedures.

The experimental arrangement, described in Appendix I, is essentially the same as used by MacDowell and Martin[1], and by Eckert and Donnelly[2]. The thin films, approximately 1.25 centimeters long, 70 microns wide and 1000 angstroms thick, were prepared by evaporating tin or indium on one-inch diameter glass substrates. The equipment and procedures for preparing the thin films are described in Appendix II.

To determine whether the specimen is in the resistive or the superconducting state, a small direct current is maintained in the circuit and the voltage drop across the specimen is measured. This current, hereafter referred to as the "dc reference current", was selected to be 5 milliamperes for the measurements reported here. This current is large enough to give a discernable potential difference across the film, but small enough to have little effect on the backswitch time.

The specimen was switched from the superconducting to the resistive state by an input current pulse. This was a square wave with a rise and fall time of less than 0.01 microsecond. The overshoot on the rise and the undershoot on the fall were less than 5 percent of the pulse height and the duration of each was approximately 0.02 microseconds (See Figure 1). A frequency of 500 pulses per second was used for all measurements reported and the remaining pulse parameters, duration and magnitude, were used as variables.

[1] MacDowell, C. R. and F. P. Martin, Effects of Silicon Monoxide Overlays on the Normal to Superconducting Transition Time in Thin Indium Films, U. S. Naval Postgraduate School Thesis, 1963: p 5.

[2] Eckert, J. A. and R. G. Donnelly. Temperature Dependence of the Normal to Superconducting Transitions, U. S. Naval Postgraduate School Thesis, 1960: p 4.

The parameters which are readily controlled are: specimen dimensions, material in contact with the specimen surface, temperature, dc reference current, external magnetic field, and the input current pulse magnitude, duration and frequency. The parameter effects which are reported on in this paper are temperature, external magnetic field, input current pulse magnitude and duration, and the effect of a silicon monoxide coating over the specimen.

For the superconductors used by the authors the transition to the superconducting state occurs below 4° K. To work in this temperature range, a cooling system consisting of two concentric Dewar flasks was used. The outer flask contained liquid air and served as an insulator, while the inner flask, in which the specimen was placed, contained liquid helium. To prevent thermal shock to the glass substrate the specimen was precooled in the vapor over and then in liquid air, prior to being immersed in the liquid helium. The Dewar flasks were also precooled and when the sample and the flasks had reached liquid air temperature, the Dewar system was assembled and the liquid helium introduced. The temperature depended on the vapor pressure of the liquid helium which was controlled and measured. The measured pressure was then converted to a temperature reading.

The effect of temperature on the backswitch time was investigated from about 4° to 1.9°K. The procedure was to cool the specimen and to measure the backswitch time as a function of the input current-pulse magnitude for a constant temperature. This was repeated for lower temperatures until the anomaly could no longer be detected without changing the other parameters. The general behavior of the backswitch time was also investigated in the neighborhood of the lambda point of helium which is

2.1°K. During this part of the investigation the duration and frequency of the input pulse and the dc reference current were kept constant.

While temperature was held constant, the effect of varying the input pulse duration was investigated. The procedure was to select an input pulse duration, and then to measure the backswitch time as a function of input-pulse magnitude. This was repeated for various durations ranging from 5 to 300 microseconds. The pulse duration investigation was repeated after the specimens had been coated with silicon monoxide.

Changes in the backswitch time in the presence of an externally applied magnetic field were also investigated. The field was applied by a set of water-cooled Helmholtz coils with the axis of the coils coinciding with the axis of the Dewar flasks. The specimen was in the center of the coils and oriented such that the length of the film was approximately normal to the axis of the coils. The procedure was to select a magnetic field and to measure the backswitch time as a function of the input current. This was performed for various magnetic field strengths at several temperatures. The range of the field strength was from zero to 300 gauss and the temperature was varied from the critical temperature to 1.9°K. The effect of the earth's magnetic field was neglected.

The effect of coating the specimen with silicon monoxide was examined by measuring the backswitch characteristics and then repeating the measurements with first one, then two coats of silicon monoxide. Each coat was approximately 0.05 microns thick. The procedures used to make the measurements were the same as those used to determine the pulse-duration effect. The use of the same specimen with and without silicon monoxide coatings eliminated any new variable which might have been introduced by coating a

new specimen.

For comparison purposes the measurements are seperated into two categories, those which could be observed during a single investigation and those which required successive repetitions. Input pulse duration, temperature, and external magnetic field effects were of the first category whereas the effects of the silicon monoxide coating were of the latter.

To determine the effect of varying a parameter which required successive repetitions of the investigation it was necessary that the experimental conditions and procedures be reproduced each time. The repetition was hindered by a tail on the backswitch voltage signal which created doubt as to when the transition to the superconducting state had taken place. This tail is illustrated in Figure 1b. A sharp shoulder on the backswitch voltage was desirable to minimize the uncertainty due to the tail. For the small dc reference currents used in this investigation a better definition of the backswitch time was obtained with thin films of relatively high resistance. The films used had resistance in the range of 2 to 15 ohms at liquid helium temperature, and the more resistive ones produced the most distinct backswitch voltage output. The general features of the backswitch anomaly appeared to be independent of these variations in resistance and were the same for all the specimens.

It was also found that the sharpness of the shoulder depended on the superconducting material, independent of the resistance. Tin gave a sharper shoulder than indium and was therefore used for most specimens. The gross features of the backswitch anomaly were the same for both tin and indium.

3. Experimental Results.

The general results of previous investigators were readily reproduced under similar experimental conditions. The anomaly reported by Lauer and Nunneley[1] was that the backswitch time versus input current curve has two well defined critical points, a maximum and a minimum (Figure 2). The maximum point was found to be decreased with the application of a silicon monoxide coating as reported by MacDowell and Martin[2]. This reduction was found to be very significant, and the application of a second coat of silicon monoxide of approximately the same thickness further reduced the maximum. Changes in the backswitch anomaly due to an external magnetic field had not been previously investigated. The input pulse duration had been considered as an insensitive parameter, however we found this to be true for only a limited portion of the anomaly. The temperature effect, in general, agreed with that found by previous investigators. Several specimens were used and the general features of the anomaly were the same for all.

The data is portrayed graphically in figures, each of which consists of a representive set of curves taken from a much larger selection. Each set was selected to simplify the figure and the other curves had the same general characteristics and were interleaved with those shown. The curves

[1] Lauer, A. C. and J. K. Nunneley. Transition Time From Resistive to Superconducting State for Thin Indium Films, U. S. Naval Postgraduate School Thesis, 1959: p 8.

[2] MacDowell, C. R. and F. P. Martin. Effects of Silicon Monoxide Overlays on the Normal to Superconducting Transition Time in Thin Indium Films, U. S. Naval Postgraduate School Thesis, 1963: p 17.

of each figure illustrate the effect of changes in one variable for one specimen. In general, the backswitch time appeared to be continuous as the input current was increased; therefore smooth curves were drawn with a minimum number of critical points included.

For the purpose of discussion the curve representing the backswitch time as a function of the magnitude of the input current will be divided into three regions as illustrated in Figure 2. The first region is from zero to the maximum backswitch time, the second is from the maximum to the minimum and the third is the region beyond the minimum. At all times the magnitude of the input current was kept within a range where there was no danger of specimen burnout due to joule heating. The maximum and minimum points will be discussed seperately. This simplifies the discussion as the effect of varying a single parameter is different in each region.

The effect of varying the pulse duration was investigated for pulses ranging from 5 to 300 microseconds in length. In Region I increases in the duration produce increases in the backswitch time as illustrated by the 28.6 milliampere curve of Figure 3. For current pulses in excess of 50 microseconds duration the backswitch time exceeded the time between pulses (1900 microseconds) for the specimens used.

Above a minimum current duration in Region II further increases have little or no effect on the backswitch time. This minimum for the specimens used was in the neighborhood of 15 to 20 microseconds as shown by the curve for 54 milliamperes in Figure 3 and 4. This corresponds to the effect of duration as reported by Lauer and Nunneley[3] who found the backswitch time

[3] Lauer, A. C., and J. K. Nunneley, Transition Time From Resistive to Superconducting State for Thin Indium Films, U. S. Naval Postgraduate School Thesis, 1959: p 6.

to be independent of the pulse duration for durations of the order of 20 microseconds. However this is the only region for which we found this to be true; the other regions show increases in the backswitch time as duration is increased.

The backswitch time as a function of pulse duration in Region III increases approximately linearly as the duration is increased, as shown by the 115 to 268 milliampere curves in Figure 4. This linear relationship existed for pulses up to 300 microseconds, the upper limit of the investigations. Due to fear of specimen burnout, it was not investigated whether the linear relationship would cease to exist or the anomaly would disappear for longer pulses. For a 300 microsecond pulse the backswitch time as a function of current is a rapidly increasing function (Figure 6).

It was found that the maximum backswitch time was a rapidly increasing function of the input pulse duration, as illustrated by Figure 5. In general for all of our specimens an input pulse of sufficient duration could be found such that the maximum backswitch time could no longer be determined as it exceeded the time between pulses, while the minimum remained unchanged. This was found to be true even for low pulse repetition rates where the time between input pulses was in excess of 0.02 seconds, which is a repetition rate of about fifty pulses per second. An exception is noted in that no significant variation in the maximum was found for changes in pulse-duration after two silicon monoxide coatings had been applied.

The minimum backswitch time was found to be independent of pulse durations up to 100 microseconds, but for longer durations the minimum occurred for slightly smaller currents (Figure 6).

Coating the specimen with silicon monoxide caused a decrease in backswitch time in Regions I and II but no effect on the minimum or in Region

III. The effect was about the same in I and II and increased for the second coating. Whether this dependence is on the number of coatings or the total thickness is not known.

The most pronounced effect of the silicon monoxide is on the maximum, which is lowered (Figure 7) and becomes less sensitive to changes in the other variables. The maximum did not change for pulse durations in excess of 100 microseconds when two coats of the silicon monoxide had been applied and changed only slightly for shorter durations (Figure 6). This effect of duration is markedly different than for uncoated specimens as previously described.

Lowering the temperature causes effects on the anomaly similar to coating the specimen with silicon monoxide. Lowering the temperature decreases the maximum until the anomaly no longer appears for a constant setting of the other parameters (Figure 9). The temperature range for which the anomaly was observable was approximately one Kelvin degree for the specimens used in this investigation. With the application of an external magnetic field the temperature at which the anomaly disappears is lowered.

In Region I the backswitch time could not be measured near the critical temperature for pulse duration in excess of 50 microseconds, as the specimens did not return to the superconducting state until the current had been increased beyond the maximum and into Region II. As the temperature was lowered this region became accessible to measurement and the backswitch time then decreased as the temperature was decreased. The effect in Region II was slight until the maximum had been lowered significantly, (Figure 9), at which point the backswitch time decreased until the anomaly disappeared. The effect here is so closely coupled with the maximum that it may be only

on the maximum and not on this region of the curve. There was no effect on the minimum and in Region III lowering the temperature caused only a slight decrease in the backswitch time.

The application of an external magnetic field was found to increase the backswitch time in Regions I and II. In the temperature range where the anomaly exists the greatest effect is on the value of the maximum and, where the anomaly had disappeared, the magnetic field caused it to reappear. This was found with small fields (0 to 300 gauss) down to approximately the lambda point of liquid helium (2.1°K). Below the lambda point the anomaly did not appear and the character of the shoulder of the backswitch voltage seemed to change. The general appearance of this shoulder was no longer smooth but showed a step effect. The backswitch time versus current curve showed the same step effect at this temperature (Figure 10). This may have been a quantum effect.

Small increases in the magnetic field caused large increases in the backswitch time at and near the maximum. This increase caused the specimen to remain in the normal state in Region I for fields of the order of 12 gauss at 3.375°K (Figure 11) and of 40 gauss at 2.706°K (Figure 12). The anomaly was not observed in the absence of the field at these temperatures. The maximum had gone from zero for no magnetic field to beyond measure for the above fields. The backswitch time in Region II also increased significantly with the application of the field. The field increased the backswitch time only slightly in Region III and at the minimum. Investigation of the magnetic field effect on the anomaly was conducted at lower temperatures than for the other variables due to the lowering of the critical temperatures as previously discussed.

The changes in the backswitch time resulting from variations in temperature, input pulse duration, magnetic field and silicon monoxide coatings have been discussed and now the general characteristics of the backswitch time versus input current curve with all effects will be considered.

The first region was characterized by instabilities and large changes in the backswitch time with small changes in any of the parameters. The potential difference across the film before the pulse was terminated did not have a constant magnitude but fluctuated for a constant value of input pulse. The backswitch voltage did not terminate sharply with a shoulder but rather an exponential tail which fluctuated in duration. Consequently no accurate time measurement could be made. The values shown on the figures are what appeared to be the average duration, and were difficult to reproduce closely in subsequent investigations. The fluctuations increased with increasing input-pulse duration but decreased with the silicon monoxide coating. For our specimens the backswitch time, for a selected value of input-pulse, was decreased by lowering the temperature, decreasing the pulse duration, or by applying silicon monoxide coatings. The opposite effect was observed with the application of an external magnetic field which caused an increase related to the magnetic field strength. Depending upon the temperature, magnetic field and the pulse duration, the backswitch may easily exceed the time interval between the pulses. This restricts the range over which the parameter variations can be studied in this region.

Region II is characterized by a stable potential difference across the film before the pulse is terminated and a stable backswitch time for any setting of the parameters. The backswitch voltage is constant in

magnitude and has a well defined shoulder near the backswitch maximum; however, the shoulder becomes less sharp as the minimum is approached. The lack of a sharp shoulder on the backswitch voltage makes the time measurement difficult, but the value of any given parameter which produces the minimum is easily measured. The backswitch time is a rapidly decreasing function of the input-pulse in this region. The backswitch time is increased by applying a magnetic field or by increasing the pulse duration and is decreased by lowering the temperature and coating the film with silicon monoxide.

In Region III all traces on the oscilloscope were stable for all settings of the parameters, as was found in Region II. The backswitch voltage did not have a shoulder near the minimum but, as the current was increased, a distinct shoulder developed. The shape of the backswitch time versus current curve near the minimum was parabolic in shape and, as the shoulder developed, the curve became nearly linear as illustrated by Figure 13. The pulse duration is the only variable that had a significant effect in this region. The backswitch time increased as the pulse duration was increased (Figure 6 and 16). The remaining variables investigated caused little or no change in the backswitch time in this region. The addition of one or more silicon monoxide coatings had no observable effect. A decrease in temperature caused only a small decrease and an increase in the magnetic field caused only a small increase in the backswitch time.

The maximum was the most easily varied point on the backswitch-time versus input-current curve. Small changes in the parameters produced large effects. Increasing the pulse duration and the magnetic field increased the backswitch time, while coating the film with silicon monoxide and

decreasing the temperature decreased the backswitch time. The large effect due to pulse duration did not appear after the film was coated twice with silicon monoxide, in fact the maximum remained constant for changes in pulse duration over 100 microseconds and changed only slightly for shorter durations (Figure 6).

The minimum backswitch time had a relatively constant value and occurred for about the same current, independent of how the parameters were varied. The slight variations of the minimum are of the same order of magnitude as the experimental error. The only observable change concerning the minimum appeared for long pulse durations. As previously discussed, increasing the input pulse duration in excess of 100 microseconds caused a slight shift in the minimum towards smaller currents.

4. Conclusions.

When a superconducting film is driven resistive by passing a current through it, there is an increase in its temperature due to joule heating, but this does not offer an explanation for the appearance of a maximum and minimum. There must be other factors influencing the backswitch time, particularly before the minimum. The backswitch time versus input-current curve can be broken up into three seperate regions, one before the maximum, one between the maximum and minimum, and one following the minimum. The region before the maximum does not appear to be an equilibrium condition as evidenced by the instabilities that exist there, and for this reason it is felt that no phenomenalistic explanation of a thermodynamic nature exists here.

The region following the minimum seems to depend predominately on the quantity of energy supplied to the specimen;that is the backswitch time increases as the current is increased or as the duration for which it acts is increased. Changes in temperature, magnetic field or addition of silicon monoxide coatings have little or no influence. It is expected that joule heating does influence the transition time from the normal to supercondut-ing state, these results are consistent with that idea.

If joule heating explains the backswitch time following the minimum, then clearly some other causes must predominate between the maximum and the minimum. The backswitch time was strongly influenced by temperature, magnetic field, and pulse duration; however, the silicon monoxide coatings attenuate this influence.

The relative magnitude of the maximum can be made very large as compared to the rest of the curve, except when it is coated with silicon monoxide of

sufficient thickness. The minimum does not seem to be greatly effected by any changes in the parameters.

A point that is not clear regarding the coatings of silicon monoxide is whether the effect of the second coating is due to the thicker coat or is due to the surface between the two coats. It is suggested that this surface dependence be investigated further. Another point that is worth examining is the effect of the small reference current. Replacing the steady current with short, small current pulses should show if the reference current has a significant effect on the backswitch anomaly.

Appendix I Experimental Equipment.

The equipment used to measure and control the various parameters was nearly the same as that used by Lauer and Nunneley[1], Eckert and Donnelly[2], and MacDowell and Martin[3]. The only addition was a set of water-cooled Helmholtz coils used to create the magnetic field. Block diagrams of each system are shown in Figures 17, 18, and 19.

The electrical measurements required a square-wave pulse generator, a variable direct current power supply, and an oscilloscope. The pulse generator was a Teletronics Type PG 200AA, which had a variable pulse magnitude, duration, and repetition frequency and also supplied the synchronization signals for the oscilloscope. A Tektronics Type-541 oscilloscope with a dual-channel plug-in pre-amplifier was used to obtain the voltage and time measurements. The dual channel permitted observation of both the input and the output pulses at the same time. Fifty-ohm coaxial cables were used for the connections between the oscilloscope, pulse generator and specimen. Fifty-ohm resistors were used to match impedance to the specimen and from the specimen to the oscilloscope. The dc reference current was provided by a standard direct-current power supply, supplemented by a limiting resistor and an ammeter.

The mechanical system consisted of two Dewar flasks with supporting jig and the necessary pressure regulating and measuring devices to obtain and

[1] Lauer, A. C. and J. K. Nunneley, Transition Time From Resistive to Superconducting State for Thin Indium Films, U. S. Naval Postgraduate School Thesis, 1959; p 4.

[2] Eckert, J. A. and R. G. Donnelly. Temperature Dependence of the Normal to Superconducting Transitions, U. S. Naval Postgraduate School, Thesis; 1960, p 4.

[3] MacDowell, C. R. and F. P. Martin. Effects of Silicon Monoxide Overlays on the Normal to Superconducting Transition Time in Thin Indium Films, U. S. Naval Postgraduate School Thesis, 1963; p 5.

measure the desired temperature, (Figure 18). The inner flask which contained the helium bath with the specimen had a sealable cover plate to which the pressure regulating and measuring equipment was attached. The pressure was controlled by a Crittenden regulating valve, connected to a 15-cubic-foot-per-minute Kenney forepump, and manual pressure regulating valves. The pressure was measured by a mercury manometer.

The magnetic field was generated by a pair of water cooled Helmholtz coils. The power supply was 100 volts direct current, regulated by limiting resistors and measured by an ammeter. The arrangement was such that the specimen was in the center of the coils and current flow thru the specimen was nearly perpendicular to the magnetic field.

Appendix II Thin Film Preparation.

The authors prepared all specimens used in the investigations by the method of vacuum evaporation. The vacuum system was that described by MacDowell and Martin[1] except that a new transformer and rheostat were installed by the authors so a higher temperature could be used for evaporating the silicon monoxide. The rheostat and transformer were wired to supply 150 amperes at 5 volts to the furnace posts. This appears to be the maximum current the furnace posts can withstand without overheating. Water cooled furnace posts would allow higher currents and hence higher furnace temperatures. This current was sufficient to evaporate the silicon monoxide without leaving a residue.

Glass disks, one inch in diameter and one eighth inch thick, were used as substrates for the thin films of tin and indium. The substrates were chemically cleaned and inspected under a microscope to insure that no foreign particles were on the substrates.

To get the desired shape of the thin film a mask was placed over the substrate. The mask was carefully cleaned with a camel hair brush and examined under a microscope to insure that there were no obstructions on the mask which might cause a discontinuity in the film. The mask was constructed from Sword stainless steel razor blades cut to the desired dimensions. Stainless steel blades were used to reduce the corrosion effect of the evaporation on the mask. The mask was designed to furnish a film having a center section 1-1/4 centimeters long, approximately 70 microns wide

[1] MacDowell, C. R., and F. P. Martin. Effects of Silicon Monoxide Overlays on the Normal to Superconducting transition Time in Thin Indium Films, U. S. Naval Postgraduate School Thesis, 1963: p 5.

and to have a wide region at the ends. (Figure 20a). The wide regions were to insure complete connection between the film and the lead contact strips in the specimen holder.

The specimen material was evaporated onto the substrate from tungsten and tantalum boats. The evaporation time was approximately five minutes for tin and indium and thirty minutes for the silicon monoxide. The evaporation took place in a bell jar at a pressure of approximately 10^{-6} millimeters of mercury. The boats used for tin and indium were dished surface sources of tungsten approximately 5 millimeters long, 5 millimeters wide, and 5 mils thick. The silicon moncxide boats were tantalum and cylindrical in shape with a three millimeter hole to reduce the large particle loss. They also acted as a surface source. Some large particles were still lost so a shield of tantalum was constructed (Figure 20b). This caused the source to act more as a directed than a surface source but the exact amount of silicon monoxide on the tin film was of little interest, only that there be a uniform coat over the entire film.

After the films were prepared they were examined under a microscope to check for large inclusions or other defects. Films with large inclusions were discarded due to fear of burnout during an investigation. The films were also checked for continuity before being used.

The thickness of the films was controlled by weighing the amount of material to be evaporated. An estimate of the thickness could be calculated by assuming a cosine law distribution, this method is described by Holland[2]. The thickness is given quite well by: $\underline{t} = \underline{m} \cos \underline{\phi} \cos \underline{\theta} \, (\underline{\pi} \underline{\rho} \underline{r}^2)^{-1}$.

[2]Holland, L. Vacuum Deposition of Thin Films. Wiley, 1956: p 147.

For our case ϕ and θ are 90°, r is 16.9 centimeters, ρ, the density of tin and indium, is 7.3 grams/cubic centimeter and of silicon monoxide is 2.15 grams/cubic centimeter and the mass evaporated m is given in Table 1.

BIBLIOGRAPHY

1. Eckert, J. A. and R. G. Donnelly. Temperature Dependence of the Normal to Superconducting Transitions. U. S. Naval Postgraduate School Thesis, 1960.

2. Holland, L., Vacuum Deposition of Thin Films. Wiley, 1956.

3. Jones, W. H., F. J. Milford and S. L. Fawcett. Status of Superconductivity. Batelle Technical Review, v. 11, January, 1963: 2-11.

4. Lane, C. T. Superfluid Physics, McGraw-Hill, 1962.

5. Lauer, A. C. and J. K. Nunneley. Transition Time from Resistive to Superconducting State for Thin Indium Films. U. S. Naval Postgraduate School Thesis, 1959.

6. MacDowell, C. R. and F. P. Martin. Effects of Silicon Monoxide Overlays on the Normal to Superconducting Transition Time in Thin Indium Films. U. S. Naval Postgraduate School Thesis, 1963.

7. Mattias, B. T., T. H. Geballe and V. P. Compton. Superconductivity. Reviews of Modern Physics, v. 35, January, 1963: 1-22.

8. Physical Research Laboratory, Space Technology Laboratories, Inc., Superconductive Properties of Thin Films, by E. C. Crittenden, J. N. Cooper, and F. W. Schmidlin. 2 November 1960. Research Report STL/TR-60-0000-NR356.

Table 1: Specimen Data

Specimen	Material Evaporated	Mass Evaporated (mg)	Resistance at 4.2°K(ohms)	Notes
9	Indium	137.9	3	
8	Tin	137.2	7	
8a	Silicon Monoxide	20.0	7	1
8b	Silicon Monoxide	23.6	7	2
17	Tin	105.8	12	

Notes:

1. Same specimen as 8 with one coating of silicon monoxide.

2. Same specimen as 8 with two coatings of silicon monoxide.

a) Input Current Pulse

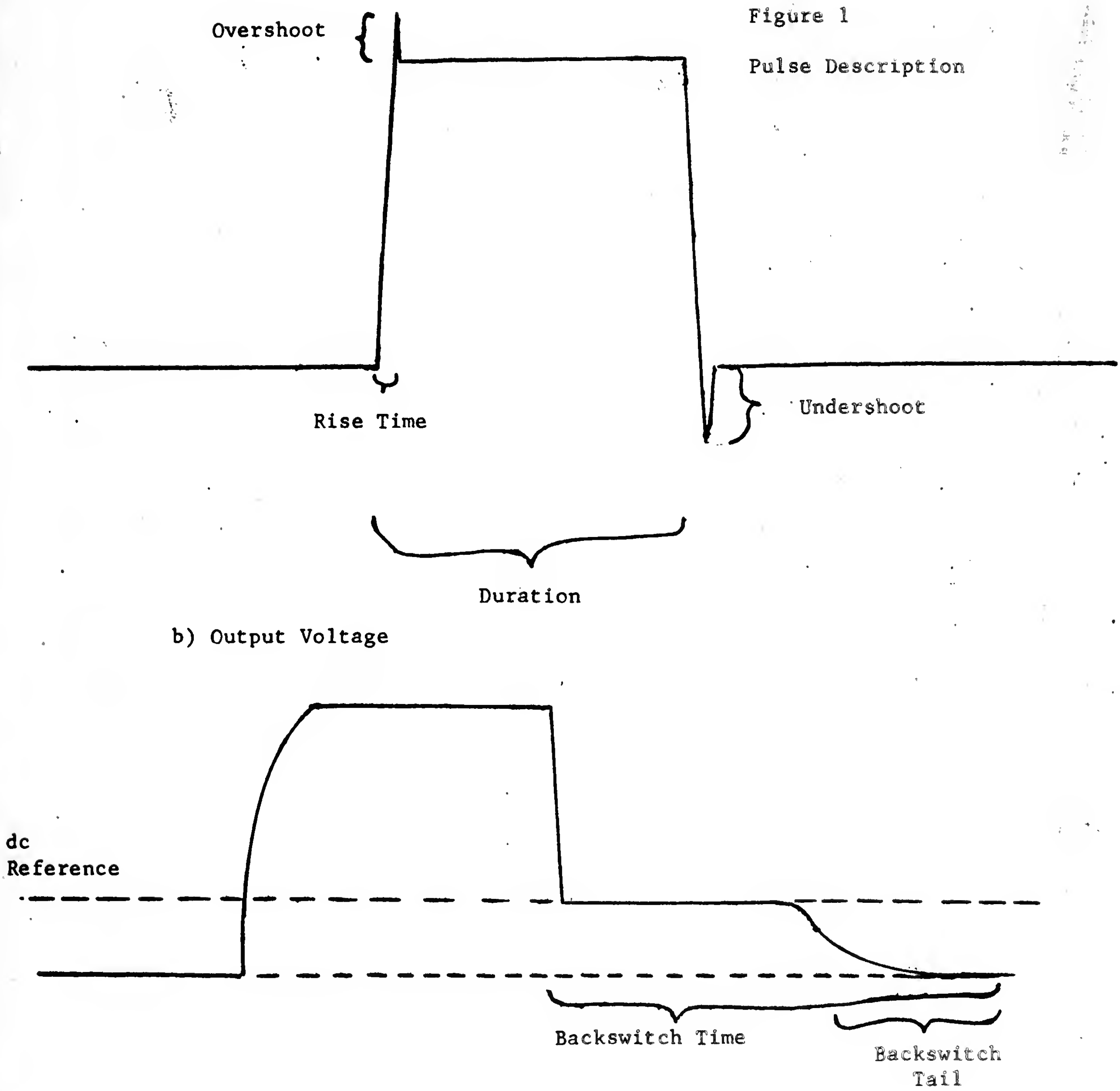
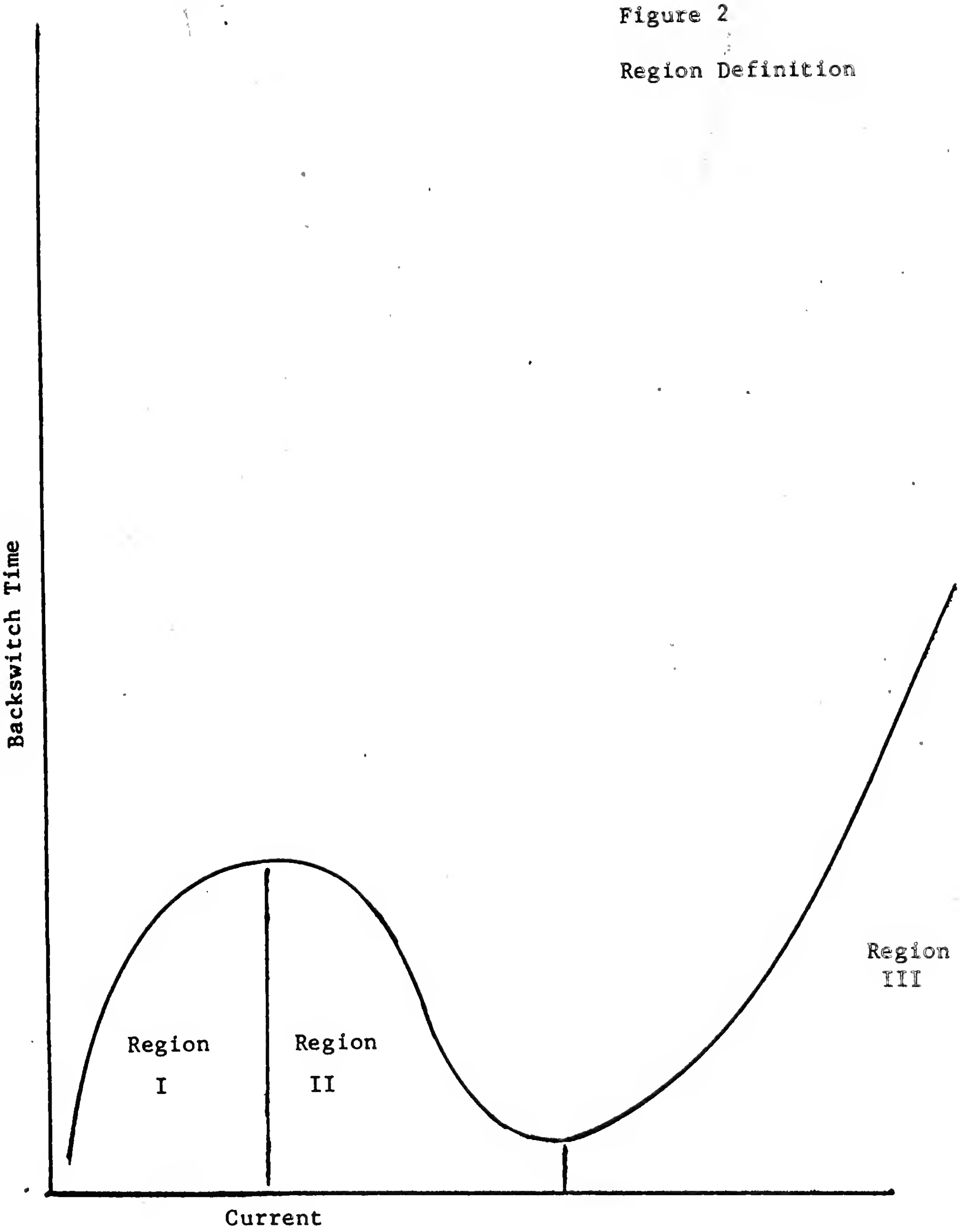


Figure 1

Pulse Description

Figure 2

Region Definition



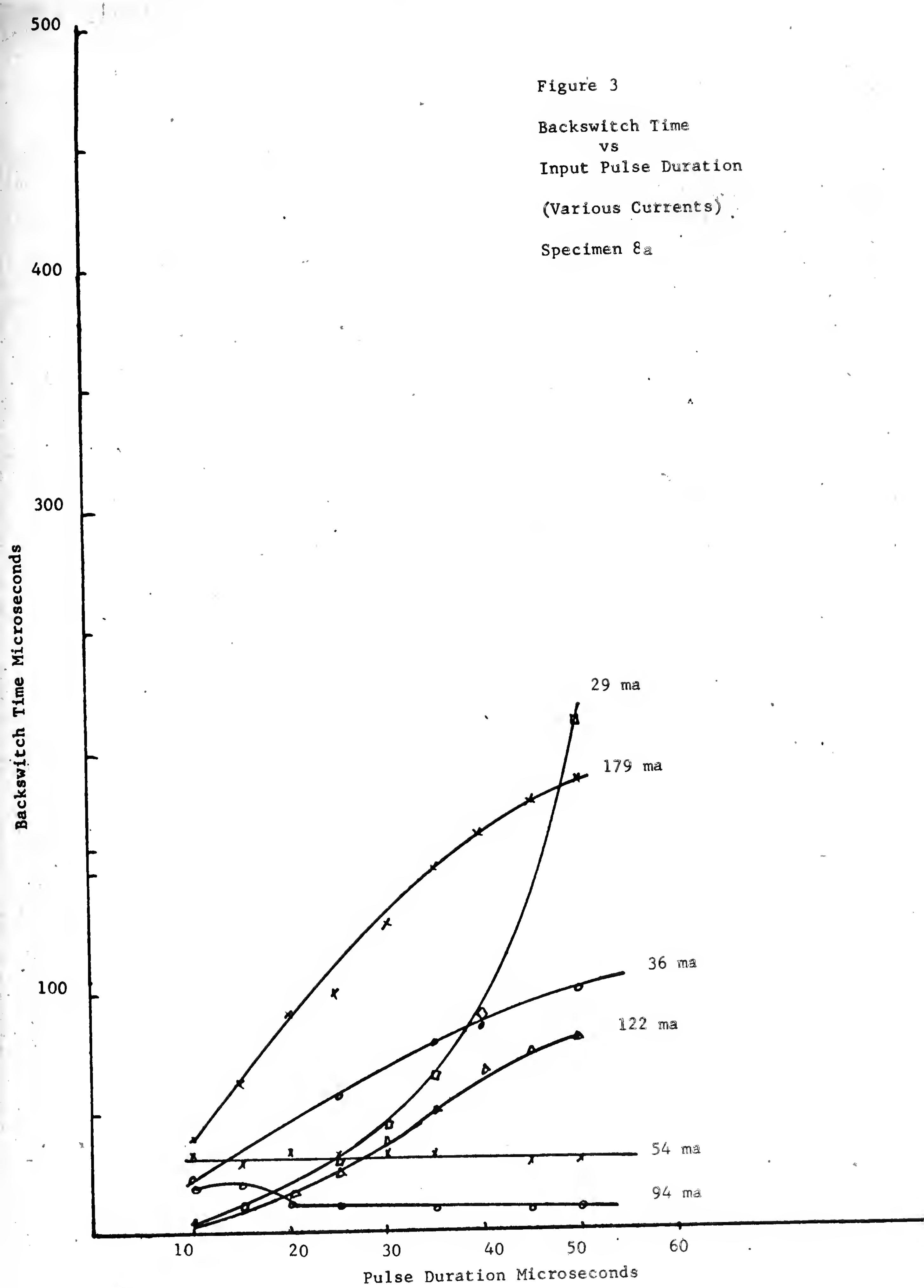
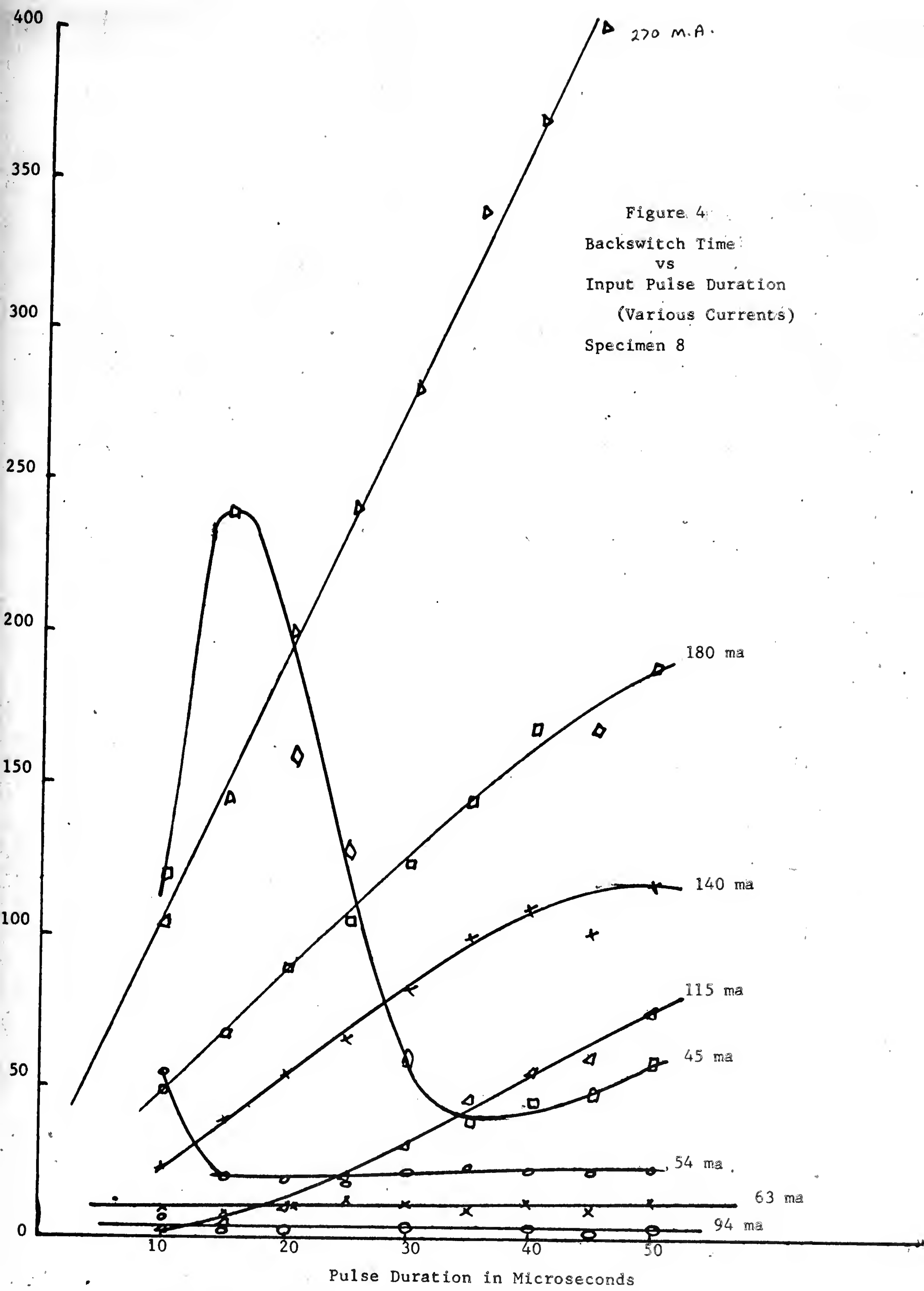
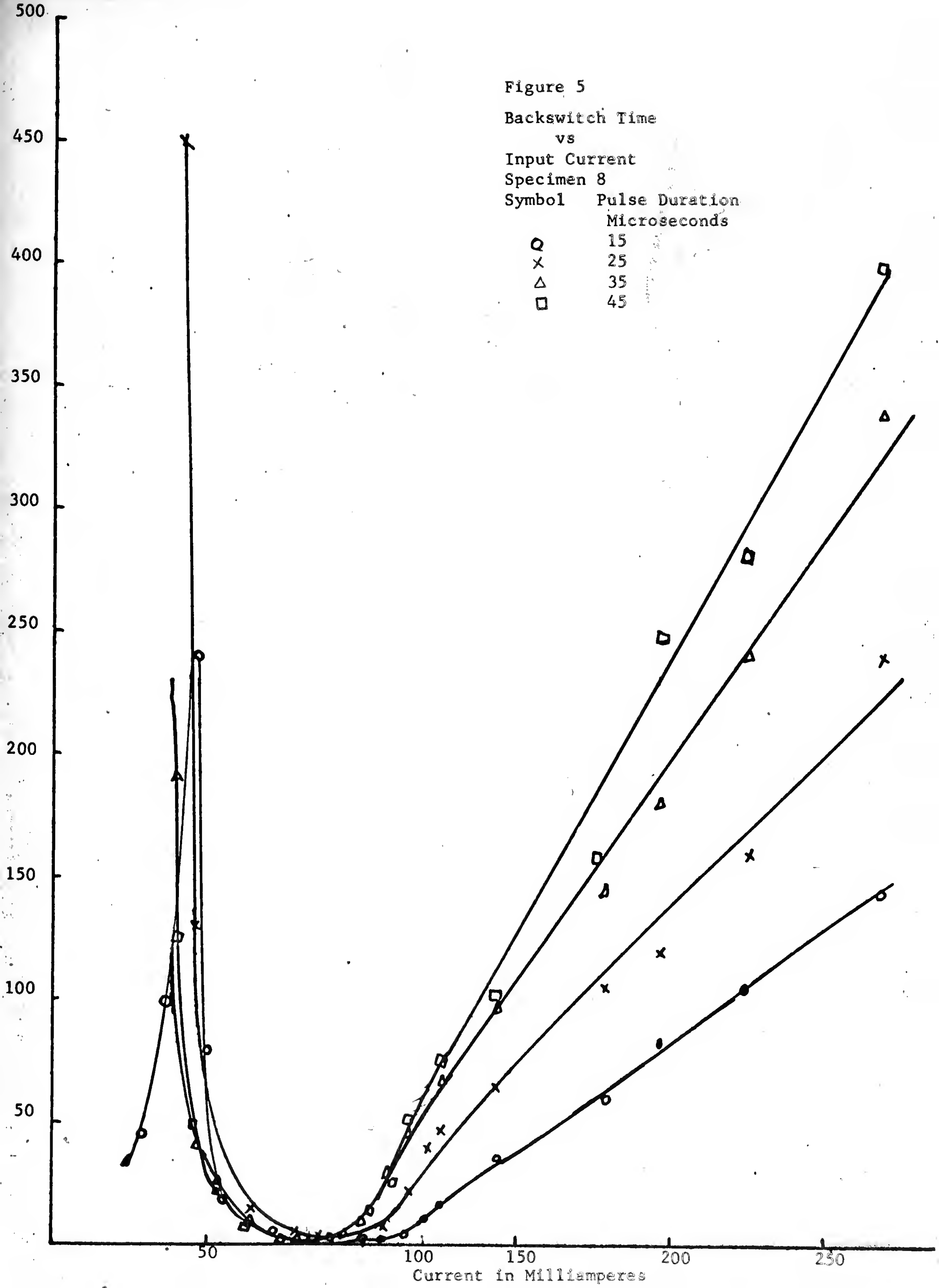
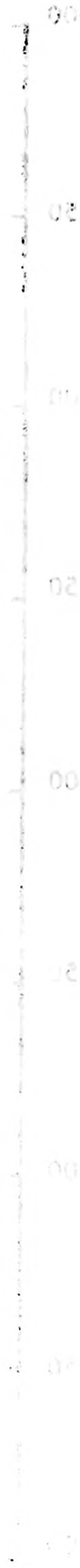


Figure 3
Backswitch Time
vs
Input Pulse Duration
(Various Currents)
Specimen 8a
500
400
300
100
Backswitch Time Microseconds
29 ma
179 ma
36 ma
122 ma
54 ma
94 ma
10
20
30
40
50
60
Pulse Duration Microseconds


400
350
300
250
200
150
100
50
0
270 M.A.
Figure 4
Backswitch Time
vs
Input Pulse Duration
(Various Currents)
Specimen 8
180 ma
140 ma
115 ma
45 ma
54 ma
63 ma
94 ma
10
20
30
40
50
Pulse Duration in Microseconds



500
450
400
350
300
250
200
150
100
50
Figure 5
Backswitch Time
vs
Input Current
Specimen 8
Symbol Pulse Duration
Microseconds
15
25
35
45
50
100
150
200
250
Current in Milliamperes



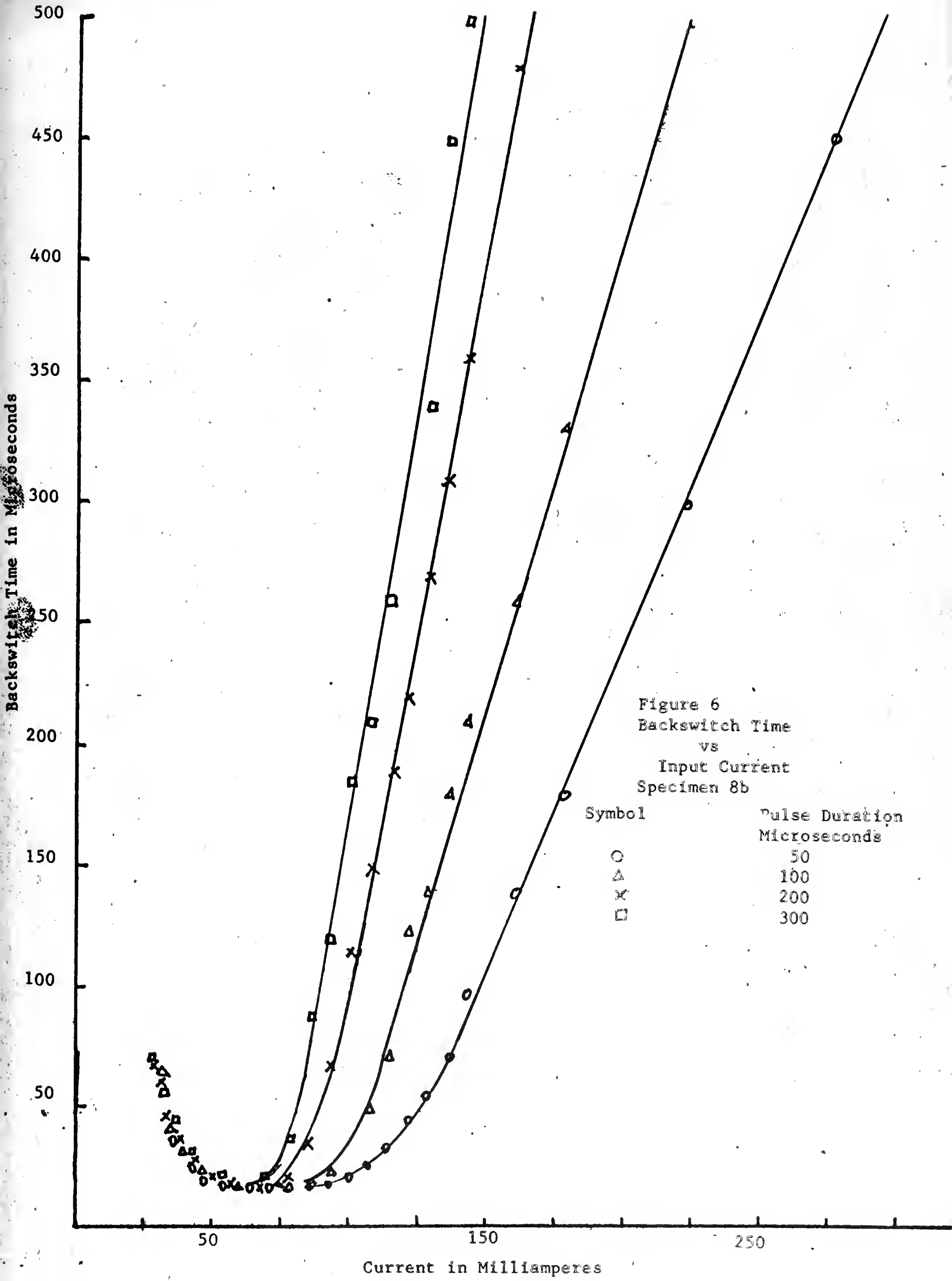


Figure 6
Backswitch Time
vs
Input Current
Specimen 8b

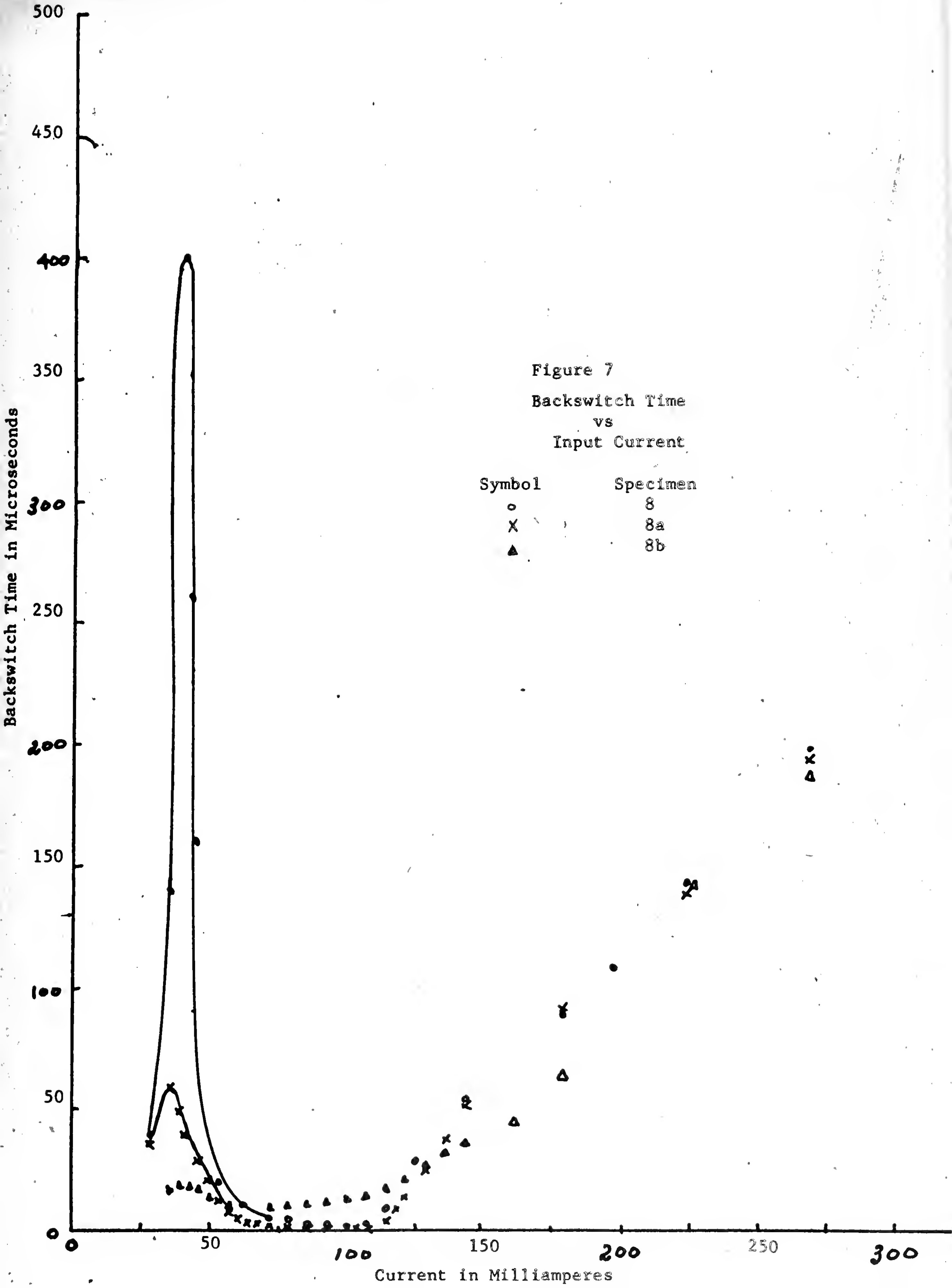


Figure 7
Backswitch Time
vs
Input Current
Symbol
Specimen
8
8a
8b
Backswitch Time in Microseconds
Current in Milliamperes
0
50
100
150
200
250
300
350
400
450
500

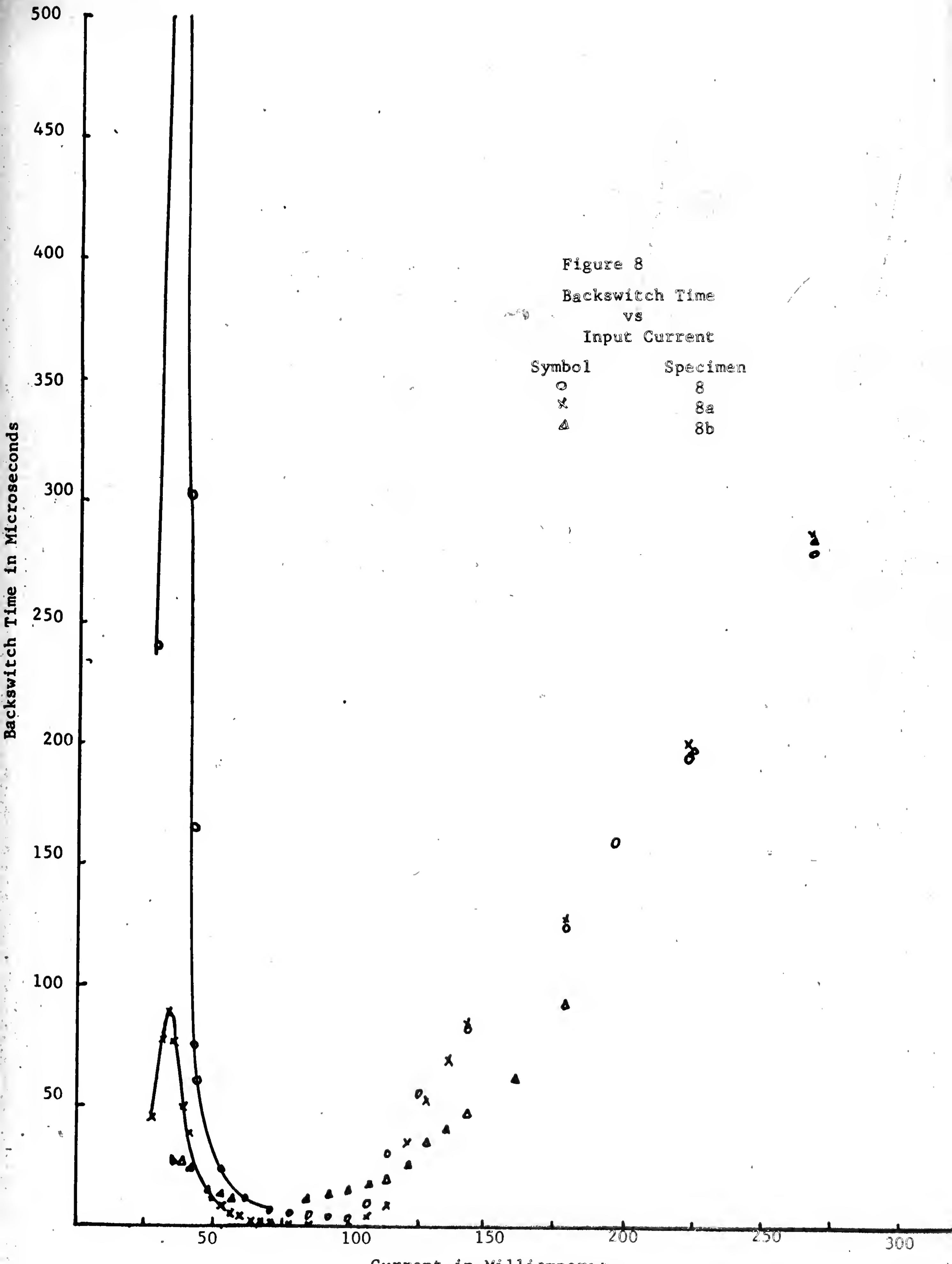
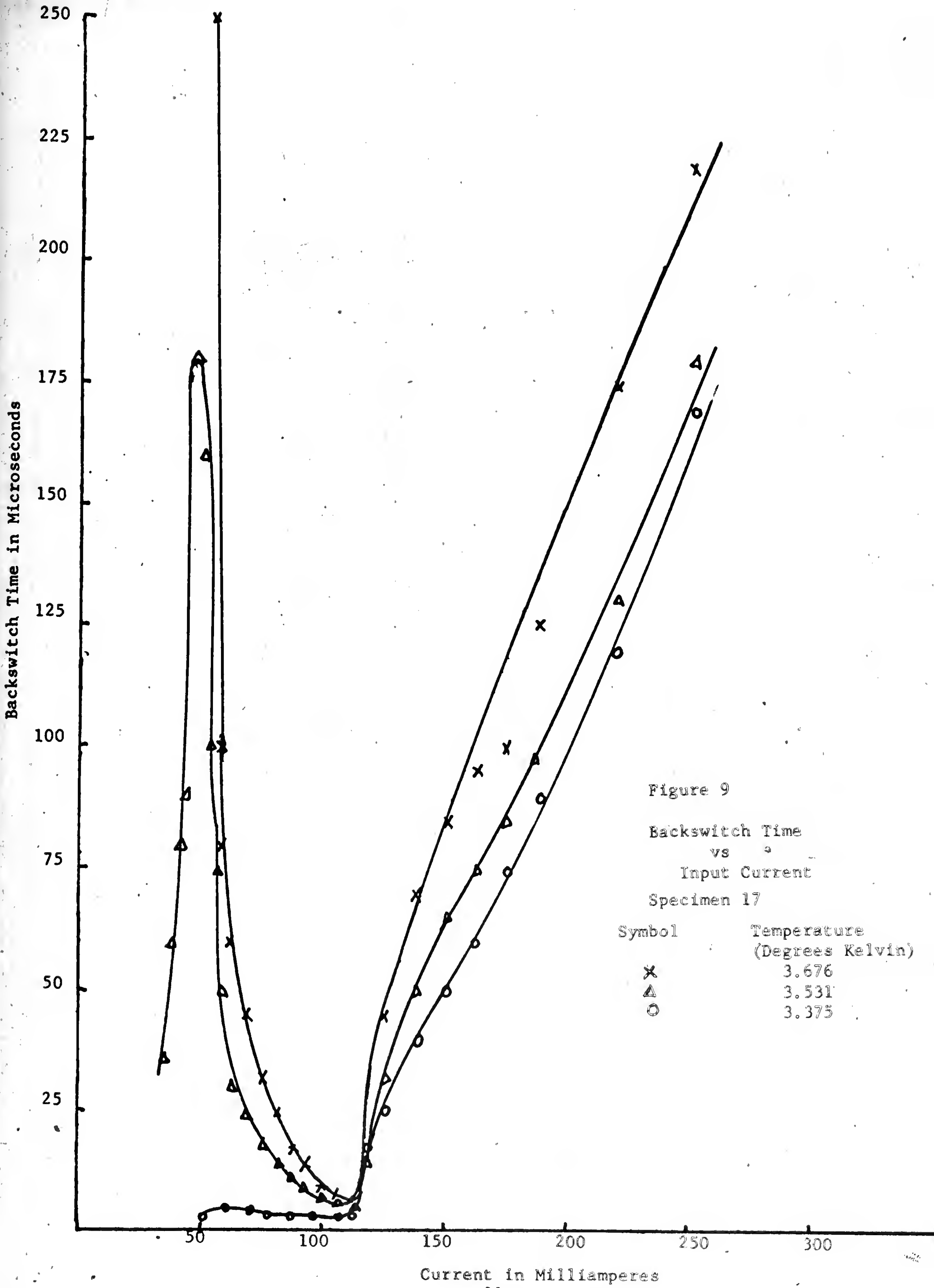


Figure 8
Backswitch Time
vs
Input Current
Symbol
Specimen
8
8a
8b
Backswitch Time in Microseconds
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
Current in Milliamperes


250
225
200
175
150
125
100
75
50
25
Backswitch Time in Microseconds
50
100
150
200
250
300
Current in Milliamperes
Figure 9
Backswitch Time
vs
Input Current
Specimen 17
Symbol
Temperature
(Degrees Kelvin)
3.676
3.531
3.375

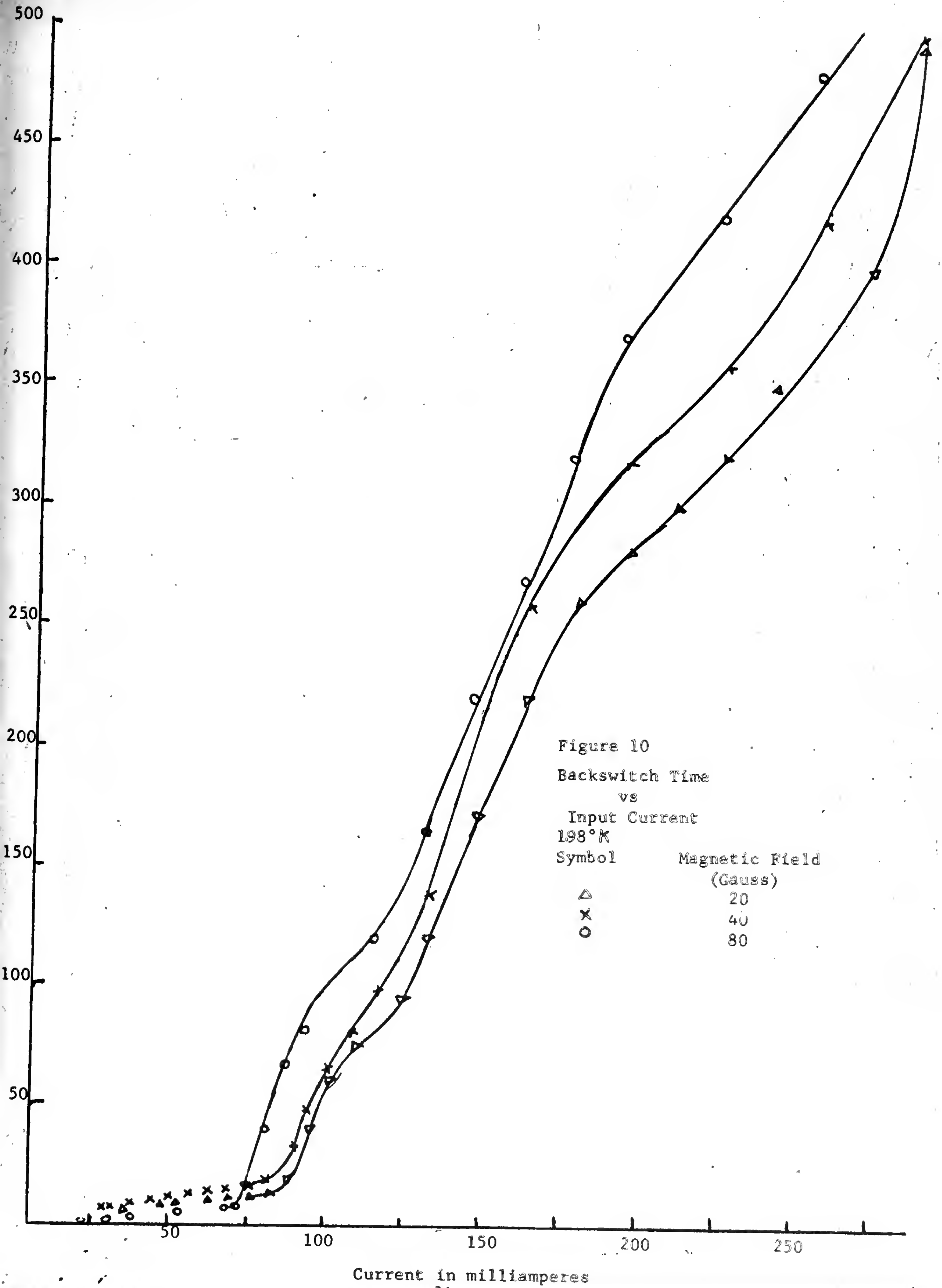


Figure 10
Backswitch Time vs Input Current
198°K

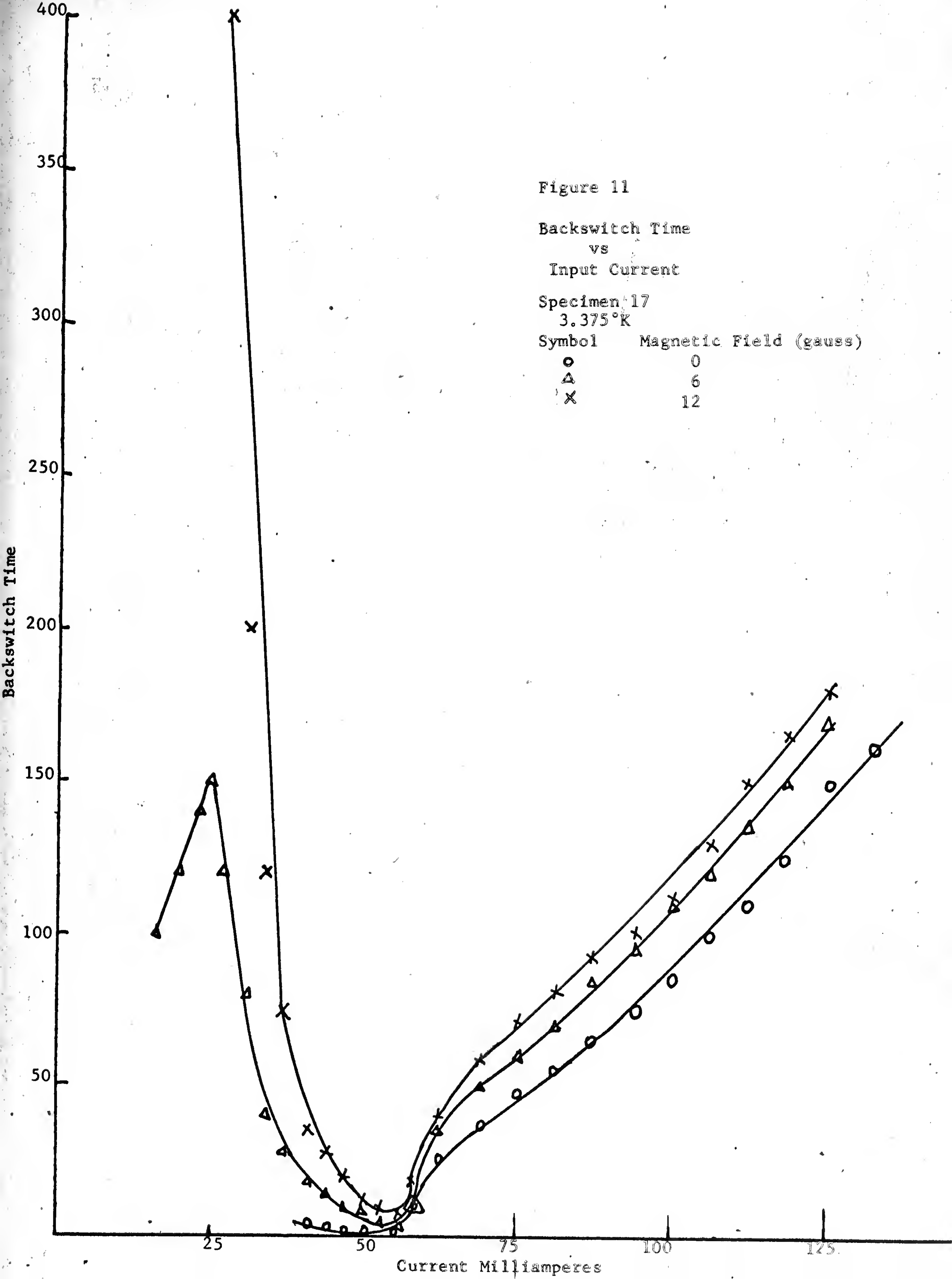


Figure 11
Backswitch Time
vs
Input Current
Specimen 17
3.375°K
Symbol Magnetic Field (gauss)
o 0
Δ 6
X 12
Backswitch Time
400
350
300
250
200
150
100
50
25
50
75
100
125
Current Milliamperes

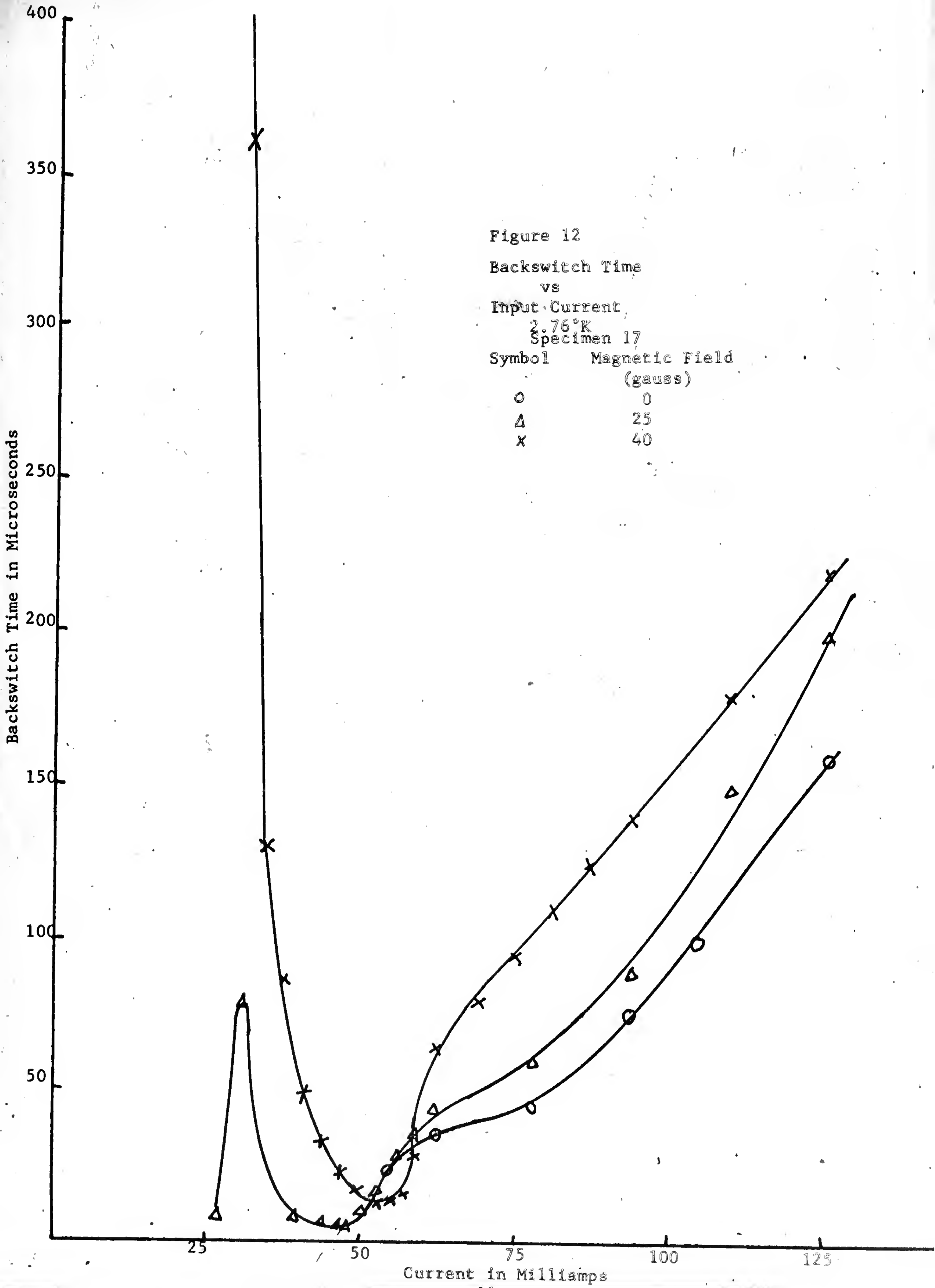


Figure 12
Backswitch Time
vs
Input Current
2.76°K
Specimen 17
Symbol Magnetic Field (gauss)
o 0
Δ 25
x 40
Backswitch Time in Microseconds
400
350
300
250
200
150
100
50
25
50
75
100
125
Current in Milliamps

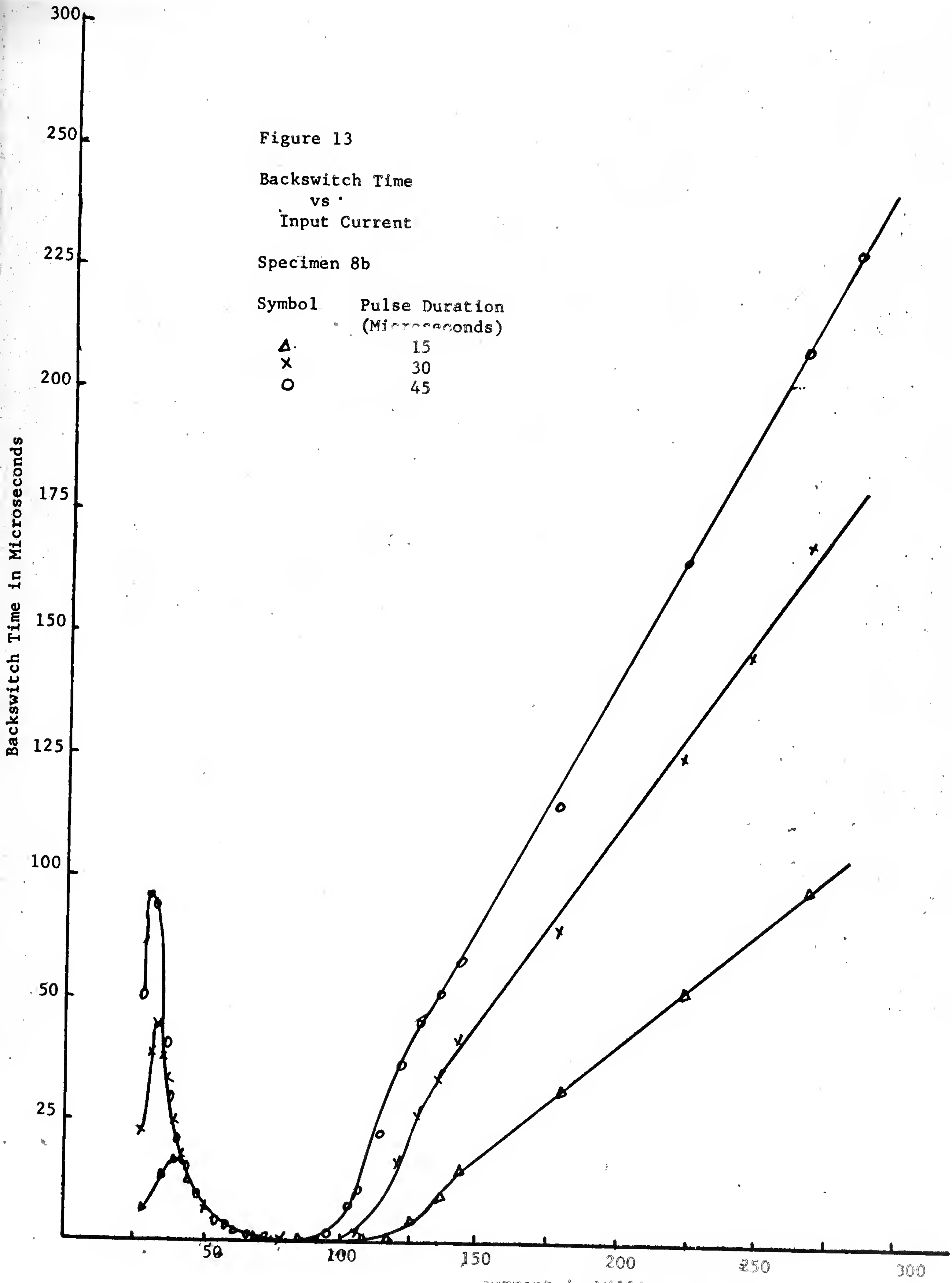


Figure 13
Backswitch Time
vs
Input Current
Specimen 8b
Symbol
Pulse Duration
(Microseconds)
15
30
45
Backswitch Time in Microseconds
300
250
225
200
175
150
125
100
50
25
50
100
150
200
250
300
Current in Milliamperes

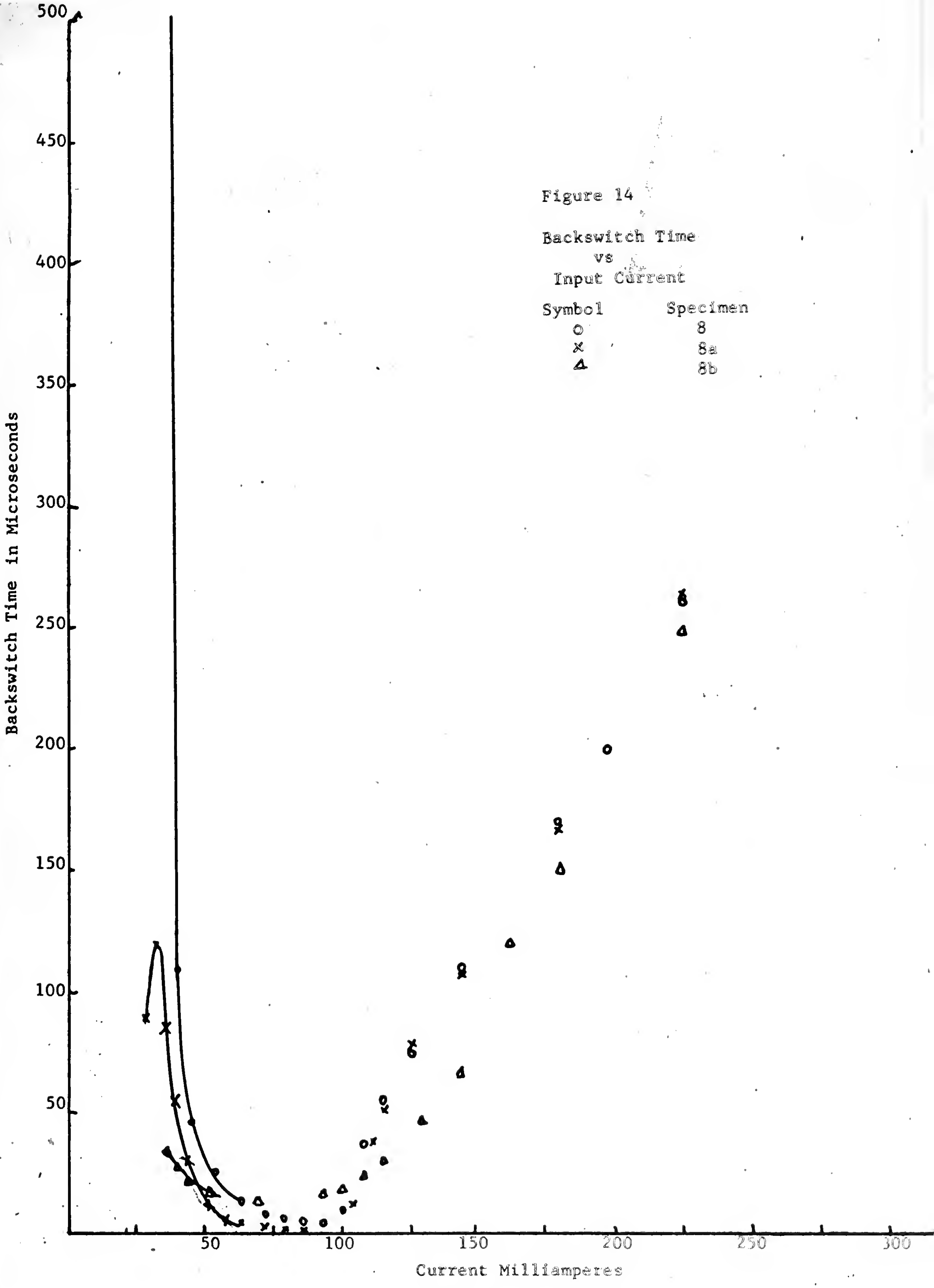
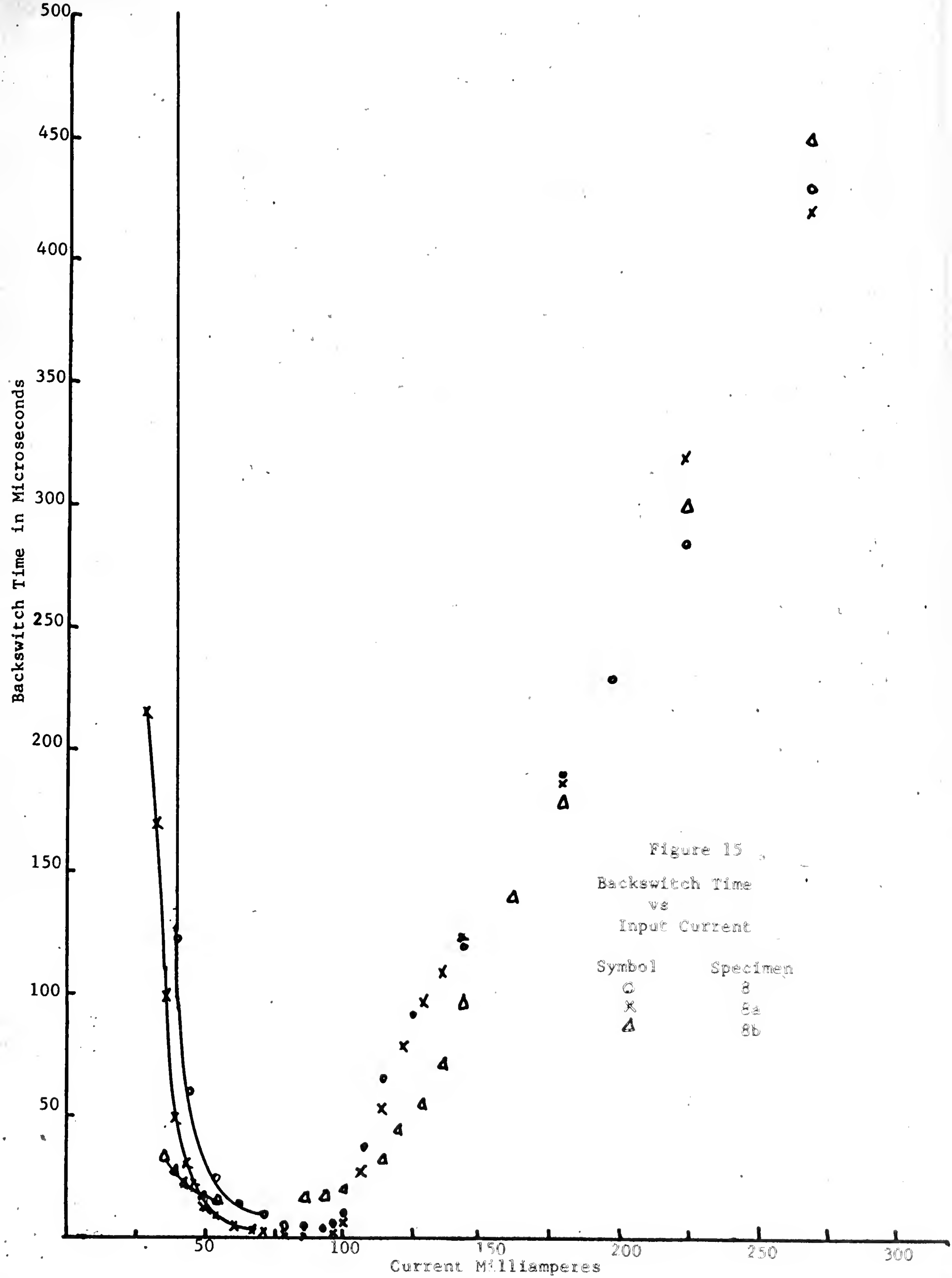


Figure 14
Backswitch Time
vs
Input Current
Symbol Specimen
o 8
x 8a
Δ 8b
Backswitch Time in Microseconds
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
Current Milliamperes


500
450
400
350
300
250
200
150
100
50
Backswitch Time in Microseconds
50
100
150
200
250
300
Current Milliamperes
Figure 15
Backswitch Time
vs
Input Current
Symbol
Specimen
O
8
X
8a
Δ
8b

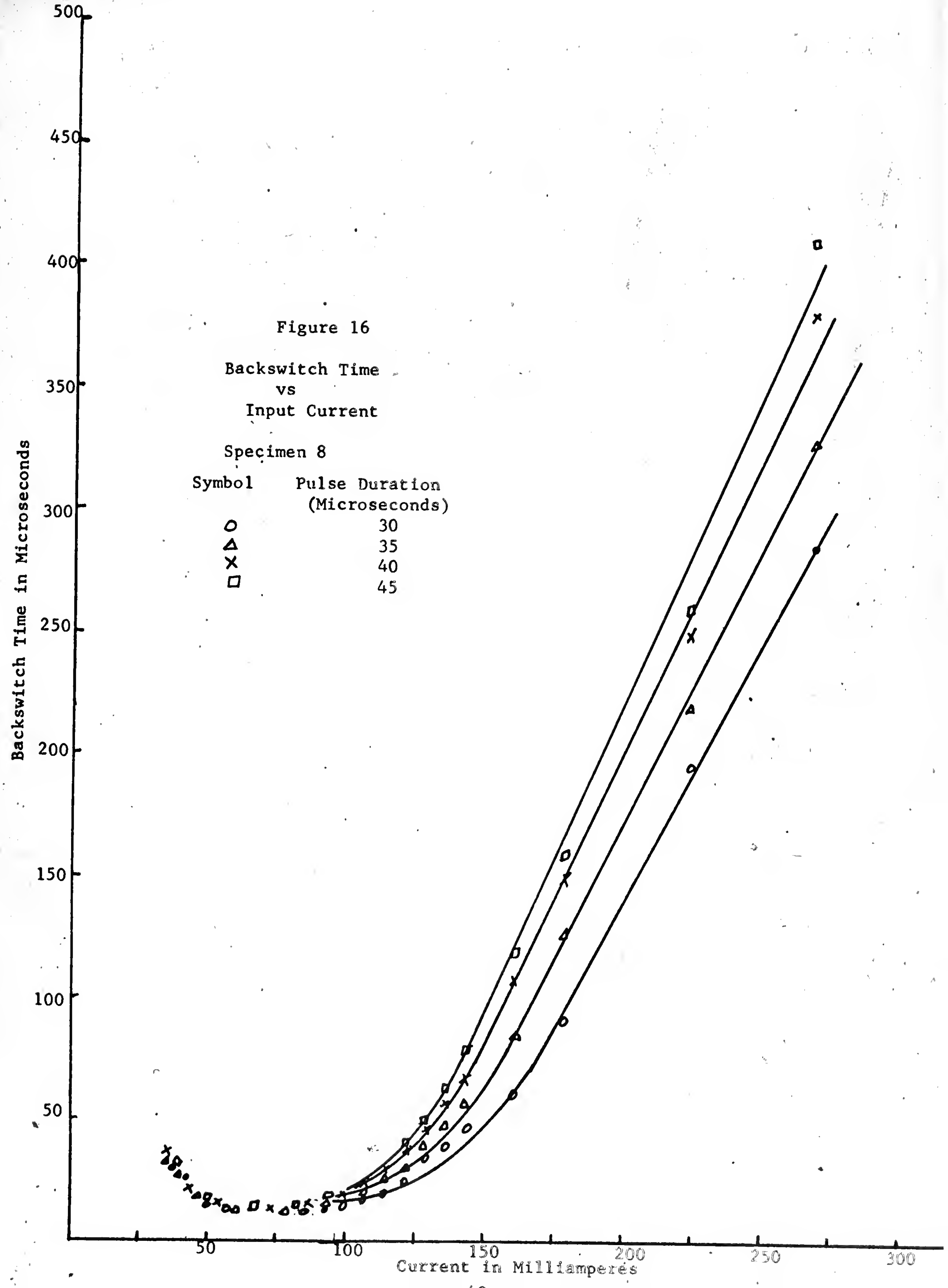


Figure 16
Backswitch Time
vs
Input Current
Specimen 8
Symbol Pulse Duration (Microseconds)
○ 30
△ 35
× 40
□ 45
Backswitch Time in Microseconds
500
450
400
350
300
250
200
150
100
50
50
100
150
200
250
300
Current in Milliamperes

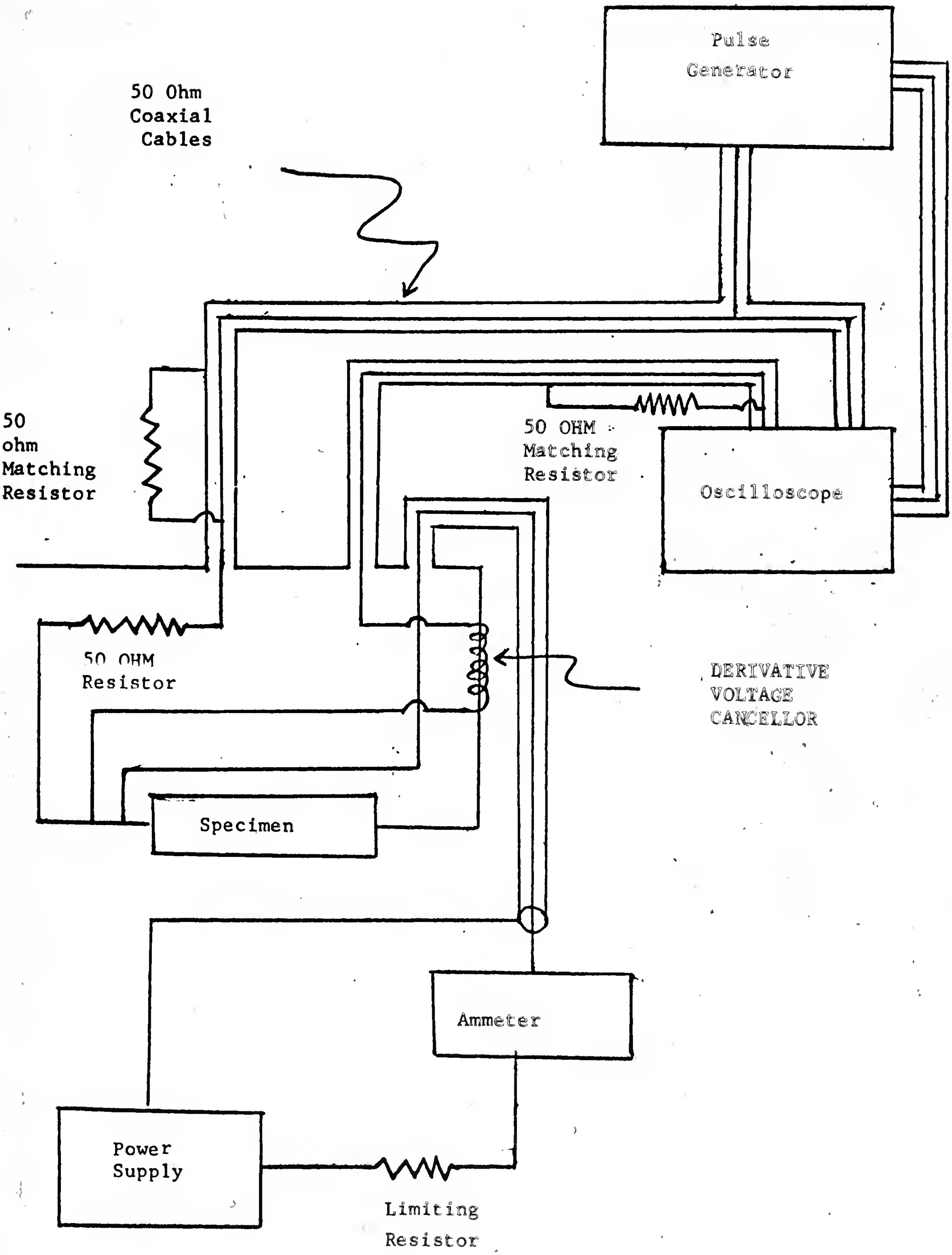

Pulse
Generator
50 Ohm
Coaxial
Cables
50
ohm
Matching
Resistor
50 OHM
Matching
Resistor
Oscilloscope
50 OHM
Resistor
DERIVATIVE
VOLTAGE
CANCELLOR
Specimen
Ammeter
Power
Supply
Limiting
Resistor

Figure 17

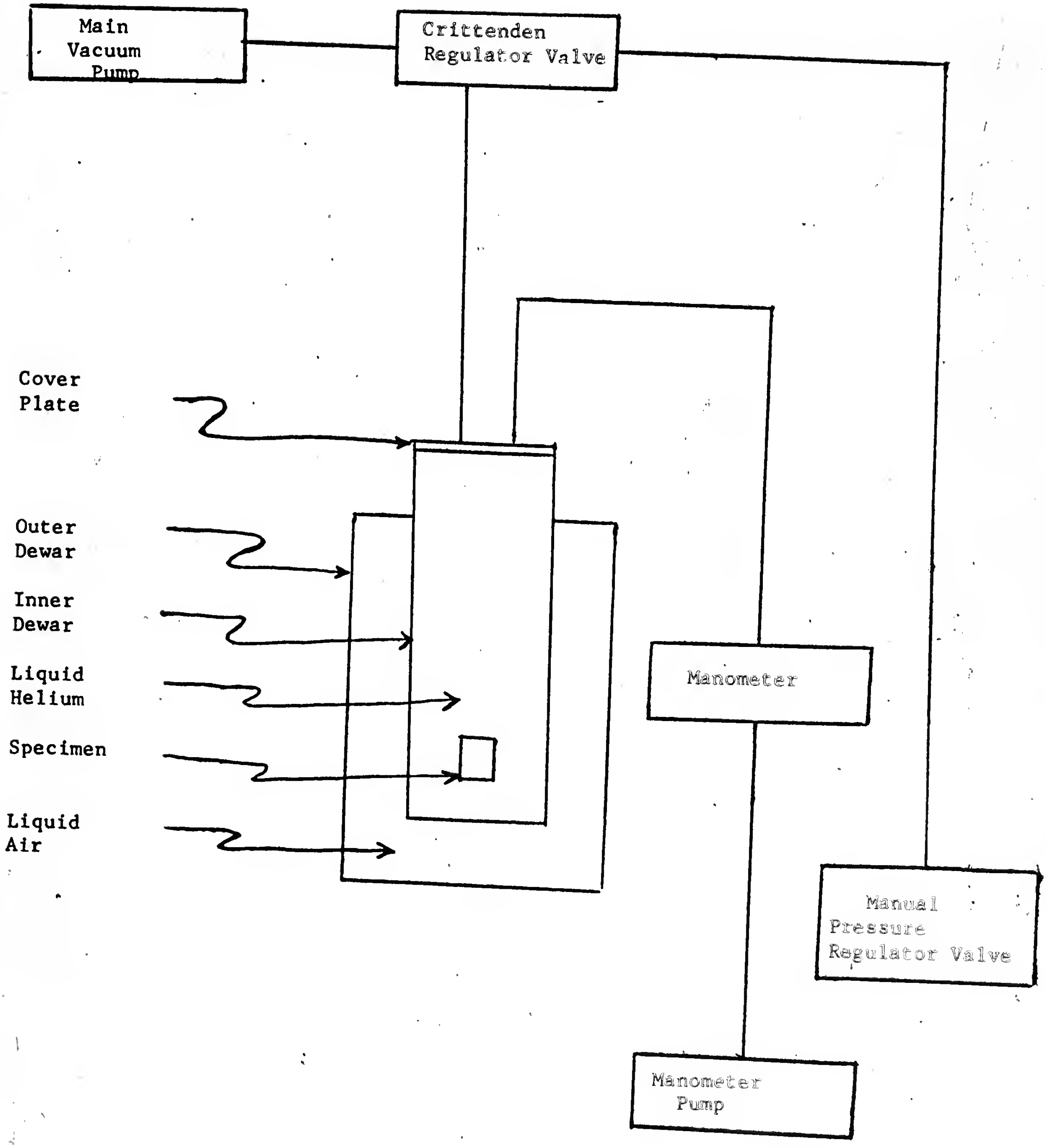

Main
Vacuum
Pump
Crittenden
Regulator Valve
Cover
Plate
Outer
Dewar
Inner
Dewar
Liquid
Helium
Specimen
Liquid
Air
Manometer
Manual
Pressure
Regulator Valve
Manometer
Pump

Figure 18

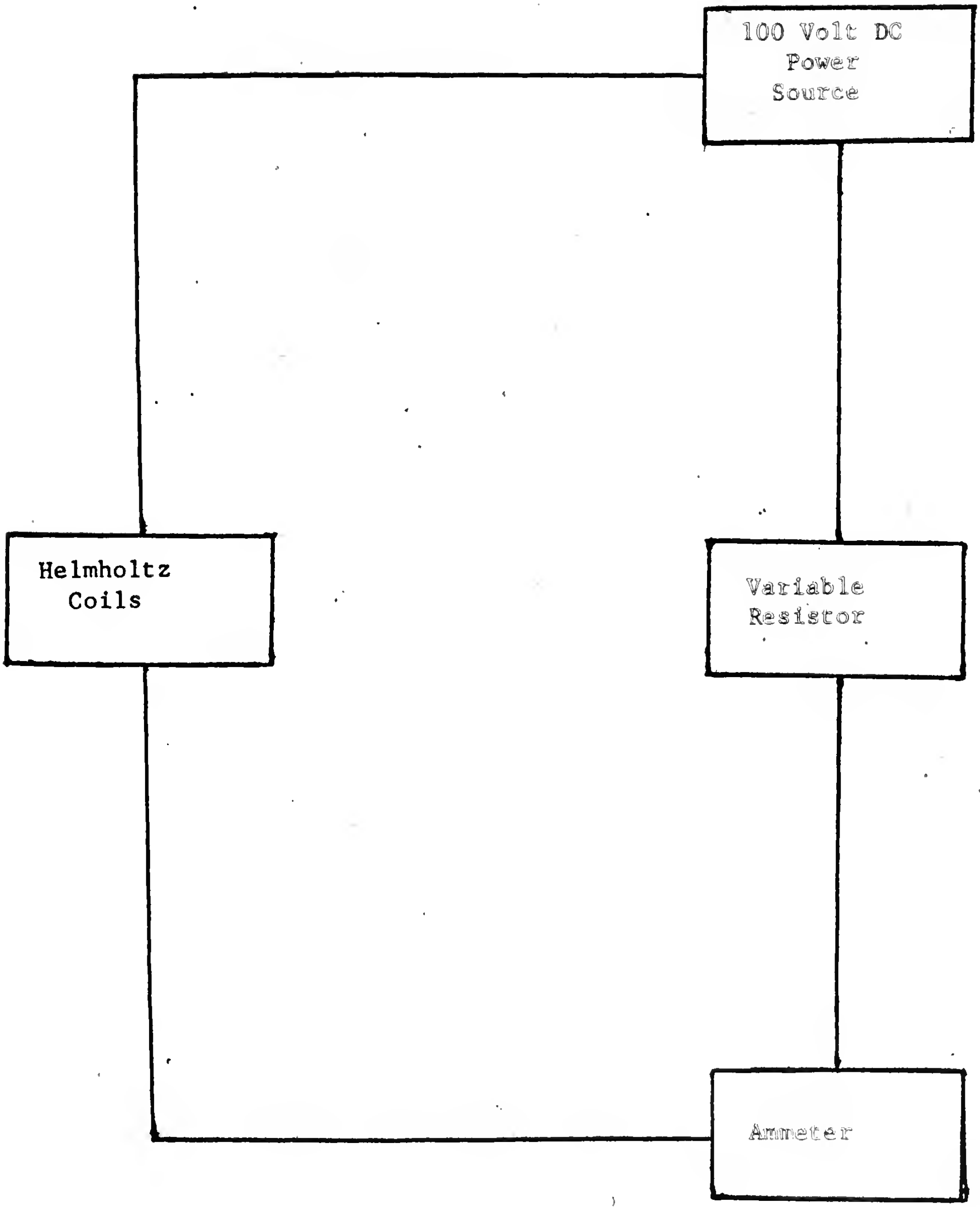
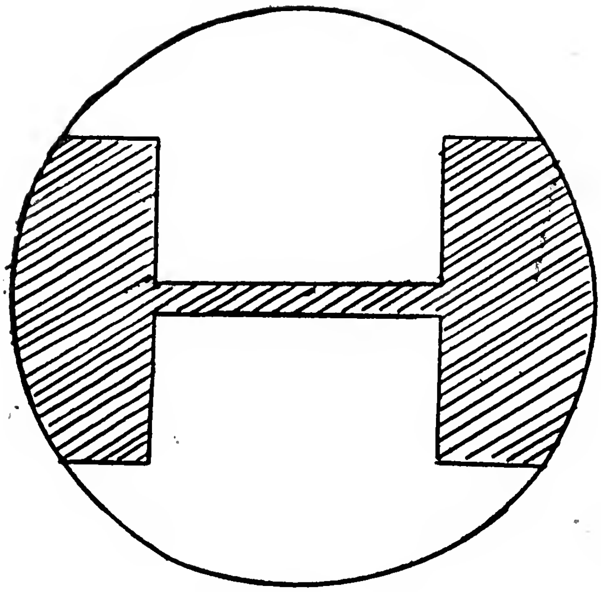
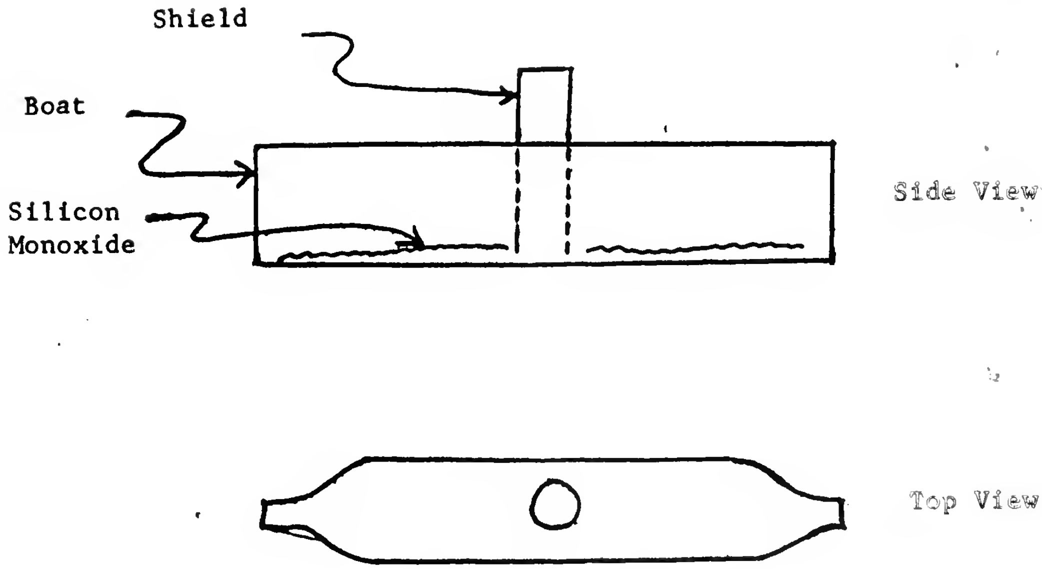

100 Volt DC
Power
Source
Helmholtz
Coils
Variable
Resistor
Ammeter

Figure 19



a) Specimen



b) Cylindrical Boat

Figure 20